

RADIATION PHYSICS NOTE #98

Isotopic Analysis Of Accelerator Induced Radioactivity In Material (Interim Report)

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September 1992

INTRODUCTION

We have undertaken a project to quantitatively characterize the isotopic constitution of the radioactivity induced in material exposed to the radiation fields of the primary and secondary beams at Fermilab. The main objective is to be able to provide a rough estimate of the activities and the half-lives of the radioactive waste that is shipped out to rad waste storage facilities. This report represents the results for the first batch of samples. Preliminary comparison with the prescription given in the low-level waste certification plan [1] is presented.

PROCEDURE

As a first step ten different activated samples of unknown history were collected from the temporary on site storage area known as the Boneyard. The activated samples and their compositions are as follows:

Stainless steel	type 304:18% Cr, 8% Ni, 2% Mn
Galvanized steel	Zinc plated steel
Copper	assumed pure copper
Brass	Cu(70%), Zn(30%)
Aluminum	assumed pure aluminum
Hevimet	W(90%), Ni(7.5%), Cu(2.5%)
Lead	lead brick (assumed pure lead)
Ceramic	Basic: MgO(90%), Al ₂ O ₃ (10%)
Concrete (Portland)	Basic: Ca(47%), O(35%), Si(10%), Al(3%), Fe(2%)
G-10	SiO ₂ (60%), Epoxy(40%)

The samples were analyzed at the activation analysis laboratory (AAL). Each sample was surveyed with a Frisker and a Bicon Analyst, and the results were recorded [2]. (See Appendix A.) The Sample was then placed in a shielded, low background, lead-brick cave and its gamma ray spectrum was measured using the High Purity germanium (HPGe) detector and EG&G Multi-Channel Analyzer system (MCA), Maestro [3]. The MCA system was calibrated using a mixed γ -ray source (SRS 40592A-266) before, in the middle, and at the end of the measurements. The MCA associated software program, Maestro, identifies, fits a linear background under and calculates the area for each peak in the spectrum. Because the Maestro's peak searching routine is not very accurate or consistent, most of the peak search for this report was done manually using the isotope tables [4].

CALCULATIONS

The activity, A_i , associated with each gamma ray peak was calculated using

$$A_i = \frac{\Sigma_{peak}}{t \times 0.037 \times BR_i \times \epsilon_i \times \Omega}$$

where Σ_{peak} is net counts in the peak. t is the detector and its associated electronics' live-time in seconds (essentially the counting time for the samples), the conversion factor from counts to picoCuries is 0.037. BR_i is the branching ratio for the i^{th} gamma ray. The efficiency ϵ_i of the HPGe is read off an efficiency curve that had been measured previously. The solid angle, Ω , subtended by the detector of radius r from a point source located a distance h away is calculated using

$$\Omega = \frac{1}{2} \left(1 - \frac{h}{\sqrt{h^2 + r^2}} \right).$$

The activities were corrected for self-absorption (which is energy dependent) of the material by use of

$$F(E) = \frac{1 - e^{-\mu(E)\rho x}}{\mu(E)\rho x},$$

where ρ and x are the density and thickness of the material, respectively, and m is the mass attenuation coefficient [5]. For composite material for which tabulated m values did not exist, the self absorption was calculated using the stoichiometric equation,

$$\mu_{composite}(E) = \sum_i w_i \mu_i(E),$$

where w_i is the percentage of the elemental composition with self absorption $\mu_i(E)$. The specific activity for each sample with mass m , was calculated using

$$Sp. Ac. = \frac{1}{m} \sum_i \frac{A_i}{F_i} \text{ (pCi/gr)}.$$

RESULTS AND DISCUSSION

It is assumed that the samples had been exposed to a beam-on accelerator environment. Little else was known about their histories (time of bombardment, etc.) except that most of them had been cooling for a long time.

The following short tables give a summary of the activation analysis of each sample.

1. Ceramic

The ceramic sample was assumed to have the basic constituents as shown on the first page, plus very small amounts of some heavier elements. As seen ^{133}Ba appears as an activated by-product, along with the predominate ^{22}Na .

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Ba-133	178.322	4.13
Na-22	4116.849	95.37
Cs-134	10.779	0.25
Cs-137	10.603	0.25

2. G-10

The small amount of ^{60}Co observed in G-10 is probably from trace amounts of impurities in the epoxy.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Na-22	289.319	99.925
Co-60	0.218	0.075

3. Aluminum

The activity observed in aluminum is virtually 100% due to ^{22}Na . There is a tiny ^{60}Co component which must be from heavier ingredient added to strengthen the aluminum alloy.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Na-22	42491.069	99.84
Co-60	69.530	0.16

4. Concrete

The net activity from the concrete sample was very low, either due to very little exposure or a too long cooling time. After ^{22}Na , ^{152}Eu was the next most active component, probably arising from a heavy impurity. In our initial analysis, ^{40}K was about 6.7% of the total relative specific activity. However, ^{40}K is, most likely, naturally occurring because of its very low production cross section, and was excluded from total activity calculations in determination of percent isotopic activity.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Eu-152	113.321	41.79
Co-60	18.217	6.72
Na-22	139.633	51.50
K-40	19.502	—

5. Copper

The major component seen in copper is ^{60}Co . Since the associated γ -ray branch of any positron emitter was not observed, the 511 keV peak was tentatively assigned to ^{22}Na .

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Na-22	154.401	0.38
Co-60	40082.677	99.62

6. Brass

In the Brass sample, the main activity was due to ^{60}Co . The 511 keV annihilation radiation was divided between ^{22}Na and ^{65}Zn , according to their relative activities.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Na-22	415.822	3.06
Mn-54	1029.011	7.56
Co-57	2134.181	15.68
Co-60	8053.693	59.18
Zn-65	1975.743	14.52

7. Stainless Steel

Different types of steel have different percentages of Cr, Ni, Mo, Zr, Mn and smaller percentages of other elements. The results for the preset sample show a large percentage of ^{44}Ti - ^{44}Sc which did not show up in galvanized steel. The annihilation peak has been divided between sodium and titanium. It is surprising that so little ^{54}Mn is observed. This may be due to a long cooling time for this sample.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Ti-44, Sc-44	2829.723	30.64
Mn-54	67.627	0.73
Co-60	5442.861	58.93
Na-22	895.176	9.69

8. Galvanized steel

The galvanized steel showed the expected zinc activity along with the nuclides that are normally produced in iron. The annihilation peak is mostly due to decay of ^{65}Zn . ^{40}K was excluded from the total activity calculations for the same reasons as given above for concrete.

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Mn-54	498.098	62.37
Zn-65	179.143	22.43
Co-60	119.374	14.95
Na-22	2.039	0.26
K-40	28.114	—

9. Hevimet (90% W)

The Hevimet sample's major activity was due to ^{172}Hf . The annihilation peak of this sample arises from the very small amounts of ^{22}Na and ^{102}Rh .

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Hf-172	1147274.9	88.39
Lu-173	108089.168	8.33
Ba-133	3997.294	0.31
Co-57	11747.73	0.91
Rh-102	1064.738	0.08
Co-60	22780.803	1.76
Na-22	695.144	0.05
Mn-54	2256.258	0.17

10. Lead

The major induced activity in lead was due ^{194}Hg , which decays into ^{194}Au . The annihilation peak is probably due to ^{102}Rh .

Nuclide	Specific Activity (pCi/gr)	Specific Activity (%)
Hg-194, Au-199	342.254	79.35
Au-196	1.317	0.31
Pb-202	1.471	0.34
Rh-102	10.868	2.52
Bi-207	62.902	14.58

Hf-172	9.451	2.19
Co-60	3.043	0.71

CONCLUSIONS

The detailed results of the analysis of the samples are given in Appendix A to this report.

The relatively long lifetime of the residual induced activity in the samples indicates that most of them have probably been cooling for a long time. As mentioned, hardly anything is known concerning the irradiation or cooling history of these samples. A more systematic study of induced radioactivity in material exposed to a high-energy accelerator environment, will require samples of known history, or (better yet) controlled activation experiments.

This report is intended to be the beginning of an on-going investigation into characterizing induced activities in different material -- specially those which are common around Fermilab. As other samples become available the tables at the end of this report will be modified and augmented.

The final table, in Appendix B, presents a comparison of the isotopic characterization of these samples with the prescription presented in the LLWCP [1]. No changes should be made in the procedures in the LLWCP based only on the results of the initial analysis presented here.

REFERENCES

1. "Low-Level Waste Certification Plan, LLWCP," Waste Activity Calculations Worksheet, Attachment E, Appendix A, p. 72. January 1992.
2. See AAL: Material Activation Logbook, No. 2, 3/5/92.
3. Reference to Maestro procedures.
4. E. Browne and R. B. Firestone "Table of Radioactive Isotopes," 1986 (publisher).
5. Bernard Shleien, Editor, The Health Physics and Radiological Health Handbook, (1989) publisher.

APPENDIX A: ACTIVITY TABLES

The following tables are the more detailed versions of the ones presented above for each sample. They show in more detail how the positron peak has been proportioned between different nuclides. The specific activity due to each peak is also given. The Frisker and Bicron readings for each sample are given at the end of each table.

Aluminum

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Ai(pCi)	Self Absorpt.	Mass(grams)	Sp. Ac(pCi/gr)
Na-22	1273.86	0.0551	1.27	2.7	1.15E+06	0.91121	56.5	2.236E+04
					<i>Na-22 Sp. Ac.(pCi/gr)=</i>		<i>22356.738</i>	
					<i>Activity(%)=</i>		<i>53.7</i>	
Annihilation	510.42	0.0837	1.27	2.7	9.89E+05	0.86929	56.5	2.013E+04
					<i>Na-22 Sp. Ac.(pCi/gr)=</i>		<i>20134.331</i>	
					<i>Activity(%)=</i>		<i>46.1</i>	
C0-60	1172.77	0.0574	1.27	2.7	1.90E+03	0.90774	56.5	3.705E+01
C0-60	1331.8	0.0538	1.27	2.7	1.68E+03	0.91318	56.5	3.248E+01
					<i>Co-60 Sp. Ac.(pCi/gr)=</i>		<i>69.530</i>	
					<i>Activity(%)=</i>		<i>0.2</i>	
						<i>Total Sp. Ac.(pCi/gr)=</i>		<i>42560.599</i>
						Frisker Count rate = 9000 cpm, Background = 35 cpm		
						Bicron Count Rate = 250000 cpm, Background = 1500 cpm		

Brass

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Self Absorpt.	Ai(pCi)	Mass(grams)	Sp. Ac(pCi/gr)
Co-57	121.76	0.3574	0.95	8.6	0.32400	4.999E+04	152.2	1.014E+03
Co-57	136.16	0.2889	0.95	8.6	0.38368	6.543E+04	152.2	1.120E+03
Co-57 Specific Activity (pCi/gr)=						2134.181		
						Activity(%)=	7.6	
Co-60	1173.52	0.0551	0.95	8.6	0.80521	4.928E+05	152.2	4.021E+03
Co-60	1332.89	0.0516	0.95	8.6	0.81596	5.008E+05	152.2	4.033E+03
Co-60 Specific Activity (pCi/gr)=						8053.693		
						Activity(%)=	65.4	
Mn-54	834.86	0.0648	0.95	8.6	0.77642	1.216E+05	152.2	1.029E+03
Mn-54 Specific Activity (pCi/gr)=						1029.011		
						Activity(%)=	8.0	
Zn-65	1115.74	0.0564	0.95	8.6	0.80127	2.359E+05	152.2	1.934E+03
Zn-65 Specific Activity (pCi/gr)=						1934.358		
						Activity(%)=	15.5	
Annihilation	510.62	0.0828	0.95	8.6	0.72670	2.899E+04	152.2	2.621E+02
Zn-65 Specific Activity (pCi/gr)=						41.385		
						Activity(%)=	0.3	
Na-22	1274.93	0.0529	0.95	8.6	0.81194	2.411E+04	152.2	1.951E+02
Na-22 Specific Activity (pCi/gr)=						195.100		
						Activity(%)=	1.6	
Annihilation	510.62	0.0828	0.95	8.6	0.72670	2.899E+04	152.2	2.621E+02
Na-22 Specific Activity (pCi/gr)=						220.722		
						Activity(%)=	1.6	
Total Specific Activity (pCi/gr)=						13608.450		
Frisker Count Rate = 5500cpm, Background = 40 cpm								
Bicron Count Rate = 120000 cpm, Background = 1600 cpm								

Ceramic

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Self Absorpt.	Ai(pCi)	Mass(grams)	Sp. Ac(pCi/gr)
Na-22	1275.02	0.05674	2.54	3.60	0.78018	7.699E+05	447.4	2.206E+03
Na-22 Specific Activity (pCi/gr)=							2205.671	
Activity(%)= 54.20								
Annihilation	510.73	0.08607	2.54	3.60	0.69223	5.919E+05	447.4	1.911E+03
Na-22 Specific Activity (pCi/gr)=							1911.178	
Activity(%)= 41.70								
Ba-133	80.87	0.10225	2.54	3.60	0.64965	1.110E+04	447.4	3.819E+01
Ba-133	355.53	0.10021	2.54	3.60	0.65481	2.017E+04	447.4	6.885E+01
Ba-133	383.53	0.09707	2.54	3.60	0.66286	2.114E+04	447.4	7.128E+01
Ba-133 Specific Activity (pCi/gr)=							178.322	
Activity(%)= 3.70								
Cs-134	604.82	0.07996	2.54	3.60	0.70935	1.169E+03	447.4	3.683E+00
Cs-134	795.93	0.07059	2.54	3.60	0.73680	2.339E+03	447.4	7.096E+00
Cs-134 Specific Activity (pCi/gr)=							10.779	
Activity(%)= 0.30								
Cs-137	661.74	0.07717	2.54	3.60	0.71737	3.403E+03	447.4	1.060E+01
Cs-137 Specific Activity (pCi/gr)=							10.603	
Activity(%)= 0.20								
Total Specific Activity (pCi/gr)=							4316.553	
Frisker Count Rate = 3000 cpm, Background = 50 cpm								
Bicron Count Rate = 120000 cpm, Background = 1700 cpm								

Concrete

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Ai(pCi)	Mass(grams)	Self Absorpt.	Sp. Ac(pCi/gr)
Eu-152	121.43	0.164	4.25	2.35	4.421E+03	553.9	0.49185	1.623E+01
Eu-152	243.75	0.1187	4.25	2.35	3.283E+03	553.9	0.58575	1.012E+01
Eu-152	343.23	0.1029	4.25	2.35	5.762E+03	553.9	0.62486	1.665E+01
Eu-152	777.73	0.0795	4.25	2.35	7.727E+03	553.9	0.69013	2.021E+01
Eu-152	962.86	0.065	4.25	2.35	6.449E+03	553.9	0.73558	1.583E+01
Eu-152	1110.47	0.0611	4.25	2.35	7.674E+03	553.9	0.74853	1.851E+01
Eu-152	1406.63	0.0541	4.25	2.35	6.751E+03	553.9	0.77257	1.578E+01
Eu-152 Specific Activity (pCi/gr)=							113.321	
Activity (%)= 40.06								
Co-60	1171.84	0.0596	4.25	2.35	3.636E+03	553.9	0.75359	8.711E+00
Co-60	1331.05	0.0559	4.25	2.35	4.035E+03	553.9	0.76629	9.506E+00
Co-60 Specific Activity (pCi/gr)=							18.217	
Activity (%)= 7.38								
Na-22	1273.15	0.0573	4.25	2.35	3.095E+04	553.9	0.76145	7.338E+01
Na-22 Specific Activity (pCi/gr)=							73.382	
Activity (%)= 29.37								
Annihilation	509.9	0.087	4.25	2.35	2.452E+04	553.9	0.66818	6.625E+01
Na-22 Annih. Specific Activity (pCi/gr)=							66.251	
Activity (%)= 23.33								
K-40	1459.59	0.0529	4.25	2.35	8.391E+03	553.9	0.77681	1.950E+01
**K-40 Specific Activity (pCi/gr)=							19.502	
Activity (%)=							-	
** Naturally occurring isotope, not counted in total activity.								
Total Specific Activity (pCi/gr)=							271.172	
Frisker Count Rate = 120 cpm, Background = 40 cpm								
Bicron Count rate = 6000 cpm, Background = 1600 cpm								

Copper

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Self Absorpt.	Ai(pCi)	Mass(grams)	Sp. Ac(pCi/gr)
Annihilation	511.42	0.0828	1.27	8.96	0.64767	1.61E+04	160.6	1.544E+02
Na-22 Specific Activity (pCi/gr)=							154.401	
Activity(%)= 0.3								
Co-60	1175.03	0.0551	1.27	8.96	0.74292	2.37E+06	160.6	1.985E+04
Co-60	1334.58	0.0516	1.27	8.96	0.75634	2.46E+06	160.6	2.024E+04
Co-60 Specific Activity (pCi/gr)=							40082.677	
Activity(%)= 99.7								
Total Specific Activity (pCi/gr)=							40237.077	
Frisker Count Rate = 20000cpm, Background = 50cpm								
Bicron Count Rate = 350000cpm, Background = 1600cpm								

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Self Absorpt.	Ai(pCi)	Mass(grams)	Sp. Ac(pCi/gr)
Na-22	1273.4	0.05715	0.3175	1.7	0.98473	1.975E+04	135.8	1.477E+02
Na-22 Specific Activity(pCi/gr)=							147.689	
<i>Activity(%)=</i>							<i>51.20</i>	
Annihilation	510.03	0.08674	0.3175	1.7	0.97695	1.879E+04	135.8	1.416E+02
Na-22 Specific Activity(pCi/gr)=							141.63	
<i>Activity(%)=</i>							<i>48.70</i>	
Co-60	1330.95	0.05579	0.3175	1.7	0.98509	2.917E+01	135.8	2.181E-01
Co-60 Specific Activity(pCi/gr)=							0.218	
<i>Activity(%)=</i>							<i>0.10</i>	
Total Specific Activity (pCi/gr)=							289.537	
Frisker Count rate = 750 cpm, Background = 50 cpm								
Bicron Count rate = 7500 cpm, Background = 1500 cpm								

Galv. Steel

nuclide	E(keV)	Mu(cm ² /gr)	x(cm)	Density(gr/cm ²)	Ai(pCi)	Fa	Mass(grams)	Sp. Ac(pCi/gr)
Mn-54	833.74	0.0657	0.397	7.86	6.931E+04	0.90415	153.9	4.981E+02
					Mn-54 Specific Activity(pCi/gr)=	498.098		
					Activity(%)=	62.07		
Zn-65	1114.34	0.0574	0.397	7.86	2.379E+04	0.91556	153.9	1.688E+02
					Zn-65 Specific Activity(pCi/gr)=	168.838		
					Activity(%)=	21.35		
Annihilation	509.95	0.0833	0.397	7.86	1.513E+03	0.88060	153.9	1.116E+01
					Zn-65 Specific Activity(pCi/gr)=	10.305		
					Zn-65 Activity(%)=	1.24		
Co-60	1172.05	0.0561	0.397	7.86	8.721E+03	0.91736	153.9	6.177E+01
Co-60	1331.26	0.0525	0.397	7.86	8.177E+03	0.92238	153.9	5.760E+01
					Co-60 Specific Activity(pCi/gr)=	119.373978		
					Activity(%)=	15.13		
K-40	1459.25	0.0497	0.397	7.86	4.008E+03	0.92632	153.9	2.811E+01
					** K-40 Specific Activity(pCi/gr)=	28.114		
					Activity(%)=	-		
Na-22	1273.45	0.0538	0.397	7.86	1.672E+02	0.92057	153.9	1.180E+00
					Na-22 Specific Activity(pCi/gr)=	1.180		
					Activity(%)=	0.10		
Annihilation	509.95	0.0833	0.397	7.86	1.513E+03	0.88060	153.9	1.116E+01
					Na-22 Specific Activity(pCi/gr)=	0.859		
					Na-22 Activity(%)=	0.10		
** Naturally occurring, not counted in total activity.								
					Total Specific Activity (pCi/gr)=	798.654		
Frisker Count Rate = 300 cpm, Background = 40 cpm								
Bicron Count Rate = 10000cpm, Background = 1500 cpm								

Hevimet

nuclide	E(keV)	Mu(cm ² /gr)	x(cm)	Density(gr/cm ²)	Ai(pCi)	Self Absorpt.	Mass(grams)	Sp. Ac(pCi/gr)
Lu-172	59.3	3.81	0.48	18.613	1.490E+06	0.02938	128.7	3.941E+05
Lu-172	181.35	1.073	0.48	18.613	2.814E+05	0.10431	128.7	2.096E+04
Lu-172	203.28	0.762	0.48	18.613	3.608E+05	0.14673	128.7	1.911E+04
Lu-172	264.78	0.481	0.48	18.613	7.649E+05	0.22953	128.7	2.589E+04
Lu-172	323.88	0.289	0.48	18.613	5.845E+05	0.35801	128.7	1.269E+04
Lu-172	330.78	0.28	0.48	18.613	6.553E+05	0.36699	128.7	1.387E+04
Lu-172	366.45	0.234	0.48	18.613	1.778E+06	0.41920	128.7	3.296E+04
Lu-172	377.49	0.219	0.48	18.613	2.108E+06	0.43885	128.7	3.732E+04
Lu-172	399.92	0.19	0.48	18.613	1.493E+06	0.48121	128.7	2.411E+04
Lu-172	410.45	0.184	0.48	18.613	1.066E+06	0.49077	128.7	1.688E+04
Lu-172	432.75	0.172	0.48	18.613	1.834E+06	0.51078	128.7	2.790E+04
Lu-172	475.26	0.149	0.48	18.613	9.690E+03	0.55276	128.7	1.362E+02
Lu-172	490.8	0.141	0.48	18.613	1.457E+06	0.56859	128.7	1.991E+04
Lu-172	528.64	0.128	0.48	18.613	1.446E+06	0.59578	128.7	1.886E+04
Lu-172	540.58	0.125	0.48	18.613	2.035E+06	0.60233	128.7	2.625E+04
Lu-172	682.46	0.0964	0.48	18.613	1.616E+06	0.67038	128.7	1.873E+04
Lu-172	698.05	0.0942	0.48	18.613	1.799E+06	0.67607	128.7	2.068E+04
Lu-172	709.78	0.0926	0.48	18.613	1.739E+06	0.68025	128.7	1.986E+04
Lu-172	723.9	0.0906	0.48	18.613	2.705E+06	0.68553	128.7	3.066E+04
Lu-172	811.07	0.0791	0.48	18.613	1.818E+06	0.71704	128.7	1.970E+04
Lu-172	901.86	0.0725	0.48	18.613	1.739E+06	0.73606	128.7	1.836E+04
Lu-172	913.22	0.0717	0.48	18.613	1.749E+06	0.73841	128.7	1.840E+04
Lu-172	930.26	0.0705	0.48	18.613	1.725E+06	0.74196	128.7	1.806E+04
Lu-172	1004.13	0.0653	0.48	18.613	1.861E+06	0.75763	128.7	1.909E+04
Lu-172	1023.84	0.0647	0.48	18.613	1.327E+06	0.75947	128.7	1.358E+04
Lu-172	1082.03	0.0628	0.48	18.613	1.691E+06	0.76533	128.7	1.717E+04
Lu-172	1095.13	0.0624	0.48	18.613	1.718E+06	0.76657	128.7	1.741E+04
Lu-172	1114.48	0.0618	0.48	18.613	1.657E+06	0.76844	128.7	1.675E+04
Lu-172	1389.24	0.0532	0.48	18.613	1.889E+06	0.79592	128.7	1.844E+04
Lu-172	1404.47	0.0527	0.48	18.613	1.472E+06	0.79756	128.7	1.434E+04
Lu-172	1442.55	0.0515	0.48	18.613	1.801E+06	0.80152	128.7	1.746E+04
Lu-172	1472.72	0.0506	0.48	18.613	3.875E+06	0.80450	128.7	3.743E+04

Hevimet

Lu-172	1491.37	0.05	0.48	18.613	1.973E+06	0.80650	128.7	1.901E+04
Lu-172	1545.3	0.0492	0.48	18.613	2.084E+06	0.80917	128.7	2.001E+04
Lu-172	1586.64	0.0487	0.48	18.613	1.981E+06	0.81085	128.7	1.898E+04
Lu-172	1624.49	0.0482	0.48	18.613	1.693E+06	0.81253	128.7	1.619E+04
Lu-172	1673.21	0.0476	0.48	18.613	1.458E+06	0.81456	128.7	1.391E+04
Lu-172	1727.22	0.047	0.48	18.613	1.580E+06	0.81659	128.7	1.503E+04
Lu-172	1917.93	0.0447	0.48	18.613	1.814E+06	0.82445	128.7	1.710E+04
Hf-172 Specific Activity (pCi/gr)=							1147274.87	
Activity(%)=							93.2	
Lu-173	100.64	4.393	0.48	18.613	1.240E+05	0.02548	128.7	3.781E+04
Lu-173	171.21	1.234	0.48	18.613	4.254E+05	0.09070	128.7	3.644E+04
Lu-173	272.06	0.448	0.48	18.613	1.068E+06	0.24528	128.7	3.383E+04
Lu-173 Specific Activity (pCi/gr)=							108089.168	
Activity(%)=							2.4	
Ba-133	302.83	0.316	0.48	18.613	6.718E+04	0.33316	128.7	1.567E+03
Ba-133	356.04	0.247	0.48	18.613	7.117E+04	0.40328	128.7	1.371E+03
Ba-133	383.87	0.211	0.48	18.613	6.134E+04	0.44994	128.7	1.059E+03
Ba-133 Specific Activity (pCi/gr)=							3997.294	
Activity(%)=							0.3	
Co-57	121.99	3.172	0.48	18.613	2.956E+04	0.03529	128.7	6.509E+03
Co-57	136.4	2.348	0.48	18.613	3.214E+04	0.04767	128.7	5.239E+03
Co-57 Specific Activity (pCi/gr)=							11747.730	
Activity(%)=							0.09	
Rh-102	475.26	0.149	0.48	18.613	9.690E+03	0.55276	128.7	1.362E+02
Rh-102	636.84	0.1028	0.48	18.613	7.818E+04	0.65422	128.7	9.285E+02
Rh-102 Specific Activity (pCi/gr)=							1064.738	
Activity(%)=							0.11	

Hevimet

Co-60	1174.86	0.0599	0.48	18.613	1.129E+06	0.77439	128.7	1.133E+04
Co-60	1334.38	0.0549	0.48	18.613	1.165E+06	0.79038	128.7	1.145E+04
Co-60 Specific Activity (pCi/gr)=							22780.803	
Activity(%)=							3.5	
Na-22	1276.25	0.0567	0.48	18.613	3.451E+04	0.78457	128.7	3.418E+02
Na-22 Specific Activity (pCi/gr)=							341.769	
Activity(%)=							0.05	
Annihilation	511.28	0.133	0.48	18.613	2.661E+04	0.58510	128.7	3.534E+02
Na-22 Specific Activity (pCi/gr) =							353.375	
Activity(%)=							0.04	
Mn-54	835.89	0.0773	0.48	18.613	2.097E+05	0.72216	128.7	2.256E+03
Mn-54 Specific Activity (pCi/gr)=							2256.258	
Activity(%)=							0.30	
TOTAL SPECIFIC ACTIVITY (pCi/gr)=							1297906.01	
Frisker Count Rate = 12000cpm, Background = 50cpm								
Bicron Count Rate (at 1.25cm) = 345000cpm, Background = 1700cpm								
Bicron Count Rate (at 2.5cm) = 230000cpm, Background = 1700cpm								
Bicron Count Rate (at 5.0cm) = 130000cpm, Background = 1700cpm								

Lead

Nuclide	E(keV)	Mu(cm ² /gr)	X(cm)	Density(gr/cm ²)	Ai(pCi)	Mass(grams)	Self Absorpt.	Sp. Ac(pCi/gr)
Au-194	292.83	0.4461	5.08	11.35	2.03E+04	25000	0.03888	2.089E+01
Au-194	327.61	0.3562	5.08	11.35	3.00E+04	25000	0.04869	2.460E+01
Au-194	481.89	0.1737	5.08	11.35	1.85E+03	25000	0.09984	7.416E-01
Au-194	620.77	0.1212	5.08	11.35	9.95E+04	25000	0.14297	2.782E+01
Au-194	644.1	0.117	5.08	11.35	9.47E+04	25000	0.14806	2.558E+01
Au-194	947.02	0.0755	5.08	11.35	1.18E+05	25000	0.22676	2.083E+01
Au-194	1102.62	0.0669	5.08	11.35	1.17E+05	25000	0.25377	1.850E+01
Au-194	1149.24	0.0651	5.08	11.35	1.50E+05	25000	0.26017	2.298E+01
Au-194	1217.59	0.0625	5.08	11.35	1.41E+05	25000	0.26994	2.095E+01
Au-194	1467.56	0.0529	5.08	11.35	1.58E+05	25000	0.31233	2.017E+01
Au-194	1592.8	0.0505	5.08	11.35	6.42E+05	25000	0.32476	7.902E+01
Au-194	1885.08	0.0469	5.08	11.35	1.52E+05	25000	0.34505	1.759E+01
Au-194	1922.93	0.0465	5.08	11.35	1.89E+05	25000	0.34744	2.174E+01
Au-194	2042.06	0.0453	5.08	11.35	1.85E+05	25000	0.35476	2.083E+01
Hg-194 Sp. Ac.(pCi/gr)= 342.254								
Activity (%)= 81.40								
Au-196	355.14	0.3086	5.08	11.35	1.85E+03	25000	0.05620	1.317E+00
Au-196 Sp. Ac.(pCi/gr)= 1.317								
Activity (%)= 0.10								
Tl-202	438.61	0.204	5.08	11.35	3.13E+03	25000	0.08502	1.471E+00
Pb-202 Sp. Ac.(pCi/gr)= 1.471								
Activity (%)= 0.10								
Rh-102	474.25	0.179	5.08	11.35	2.60E+03	25000	0.09689	1.073E+00
Rh-102	630.32	0.1195	5.08	11.35	4.46E+03	25000	0.14499	1.229E+00
Rh-102	696.32	0.1074	5.08	11.35	5.47E+03	25000	0.16116	1.356E+00
Rh-102	765.65	0.0948	5.08	11.35	4.82E+03	25000	0.18218	1.057E+00
Rh-102	1045.5	0.0691	5.08	11.35	1.04E+04	25000	0.24632	1.684E+00
Rh-102	1102.62	0.0669	5.08	11.35	1.19E+04	25000	0.25377	1.882E+00
Rh-102	1111.53	0.0665	5.08	11.35	7.57E+03	25000	0.25517	1.187E+00

Lead

<p>Rh-102 Sp. Ac.(pCi/gr)= 9.469 Activity (%)= 1.80</p>								
Annihilation	510.02	0.1574	5.08	11.35	3.85E+03	25000	0.11018	1.399E+00
<p>Rh-102 Sp. Ac.(pCi/gr)= 1.399 Activity (%)= 0.10</p>								
Bi-207	568.62	0.1363	5.08	11.35	7.29E+04	25000	0.12720	2.292E+01
Bi-207	1062.42	0.0684	5.08	11.35	1.31E+05	25000	0.24865	2.107E+01
Bi-207	1768.84	0.0484	5.08	11.35	1.59E+05	25000	0.33634	1.891E+01
<p>Bi-207 Sp. Ac.(pCi/gr)= 62.902 Activity (%)= 13.60</p>								
Lu-172	809.05	0.0877	5.08	11.35	1.07E+04	25000	0.19650	2.186E+00
Lu-172	899.54	0.0797	5.08	11.35	1.43E+04	25000	0.21541	2.646E+00
Lu-172	910.83	0.0787	5.08	11.35	1.33E+04	25000	0.21802	2.433E+00
Lu-172	1092.3	0.0673	5.08	11.35	1.38E+04	25000	0.25239	2.186E+00
<p>Hf-172 Sp. Ac.(pCi/gr)= 9.451 Activity (%)= 1.90</p>								
Co-60	1172	0.0642	5.08	11.35	1.18E+04	25000	0.26348	1.791E+00
Co-60	1331.08	0.0582	5.08	11.35	9.00E+03	25000	0.28761	1.252E+00
<p>Co-60 Sp. Ac.(pCi/gr)= 3.043 Activity (%)= 0.70</p>								
<p>Total Specific Activity(pCi/gr)= 431.306</p>								
<p>Frisker Count Rate = 450 cpm, Background = 50 cpm</p>								
<p>Bicron Count Rate = 11000 cpm, Background = 1500 cpm</p>								

Steel

nuclide	E(keV)	Mu(cm ² /gr)	x(cm)	Density(gr/cm ²)	Ai(pCi)	Self Absorpt.	Mass(grams)	Sp. Ac(pCi/gr)
Ti-44	67.79	0.9644	0.9525	8.4972	1.506E+04	0.12806338	138.7	8.479E+02
Ti-44	78.23	0.6485	0.9525	8.4972	1.897E+04	0.18952269	138.7	7.217E+02
Ti-44	1156.47	0.0564	0.9525	8.4972	7.328E+04	0.80286244	138.7	6.581E+02
					Ti-44 Specific Activity (pCi/gr)= 2227.577			
					Activity(%)= 12.2			
Annihilation	510.4	0.0833	0.9525	8.4972	1.083E+05	0.7274356	138.7	1.073E+03
					Ti-44 Specific Activity (pCi/gr)= 602.146			
					Activity(%)= 6.9			
Mn-54	834.48	0.0657	0.9525	8.4972	7.275E+03	0.77559847	138.7	6.763E+01
					Mn-54 Specific Activity (pCi/gr)= 67.627			
					Activity(%)= 0.8			
Co-60	1172.8	0.0561	0.9525	8.4972	2.965E+05	0.80376394	138.7	2.660E+03
Co-60	1332.03	0.0525	0.9525	8.4972	3.145E+05	0.81469222	138.7	2.783E+03
					Co-60 Specific Activity (pCi/gr)= 5442.861			
					Activity(%)= 69.3			
Na-22	1274.08	0.0538	0.9525	8.4972	4.767E+04	0.81072231	138.7	4.239E+02
					Na-22 Specific Activity (pCi/gr)= 423.932			
					Activity(%)= 5.4			
Annihilation	510.4	0.0833	0.9525	8.4972	1.083E+05	0.7274356	138.7	1.073E+03
					Na-22 Specific Activity (pCi/gr)= 471.244			
					Activity(%)= 5.4			
					Total Specific Activity (pCi/gr)= 9235.38701			
					Frisker Count rate = 4500 cpm, Background = 30 cpm			
					Bicron Count Rate = 85000, Background = 1300 cpm			

APPENDIX B: COMPARISON WITH LLWCP FORM

Comparison with LLWCP

Comparison With Prescription For Isotope Characterization From LLWCP, Appendix A											
Material				Isotopic %							
STEEL, COPPER		Na-22	Ti-44, Sc-44	Mn-54	Co-57	Co-60	Zn-65				
<i>Present Report</i>											
Stainless Steel		9.69	30.6	0.73		58.9					
Galvan. Steel		0.25		62.5		15	22.5				
Copper		0.38				99.62					
Brass		3.06		7.56	15.68	59.18	14.52				
<i>From LLWCP</i>											
Steel				40		60					
Copper				20		60	20				
Al, CERAMIC, CONCRETE		Na-22	Co-60	Ba-133	Eu-152						
<i>Present Report</i>											
Aluminum		100									
Ceramic		95.4		4.1							
Concrete		51.5	6.72		41.79						
G-10		100									
<i>From LLWCP</i>											
Aluminum		100									
LEAD, TUNGSTEN		Co-57	Co-60	Rh-102	Ba-133	Hf-172	Hf-175	Lu-173	Hg-194, Au-194	Hg-203	Bi-207
<i>Present Report</i>											
Lead			0.7	2.52		2.19			79.35		14.58
Tungsten		0.91	1.76	0.1	0.3	88.4		8.3			
<i>From LLWCP</i>											
Lead									60		40